



Comparison of Ear-Canal Reflectance and Umbo Velocity in Patients With Conductive Hearing Loss: A Preliminary Study

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Abstract: **OBJECTIVE::** The goal of the present study was to investigate the clinical utility of measurements of ear-canal reflectance (ECR) in a population of patients with conductive hearing loss in the presence of an intact, healthy tympanic membrane and an aerated middle ear. We also sought to compare the diagnostic accuracy of umbo velocity (VU) measurements and measurements of ECR in the same group of patients. **DESIGN::** This prospective study comprised 31 adult patients with conductive hearing loss, of which 14 had surgically confirmed stapes fixation due to otosclerosis, 6 had surgically confirmed ossicular discontinuity, and 11 had computed tomography and vestibular evoked myogenic potential confirmed superior semicircular canal dehiscence (SCD). Measurements on all 31 ears included pure-tone audiometry for 0.25 to 8 kHz, ECR for 0.2 to 6 kHz using the Mimosa Acoustics HearID system, and VU for 0.3 to 6 kHz using the HLV-1000 laser Doppler vibrometer (Polytec Inc, Waldbronn, Germany). We analyzed power reflectance $|ECR|$ as well as the absorbance level $= 10 \times \log_{10}(1 - |ECR|)$. All measurements were made before any surgical intervention. The VU and ECR data were plotted against normative data obtained in a companion study of 58 strictly defined normal ears (Rosowski et al., 2011). **RESULTS::** Small increases in $|ECR|$ at low-to-mid frequencies (400-1000 Hz) were observed in cases with stapes fixation, while narrowband decreases were seen for both SCD and ossicular discontinuity. The SCD and ossicular discontinuity differed in that the SCD had smaller decreases at mid-frequency (1000 Hz), whereas ossicular discontinuity had larger decreases at lower frequencies (500-800 Hz). SCD tended to have less air-bone gap at high frequencies (1-4 kHz) compared with stapes fixation and ossicular discontinuity. The $|ECR|$ measurements, in conjunction with audiometry, could successfully separate 28 of the 31 cases into the three pathologies. By comparison, VU measurements, in conjunction with audiometry, could successfully separate various pathologies in 29 of 31 cases. **CONCLUSIONS::** The combination of $|ECR|$ with audiometry showed clinical utility in the differential diagnosis of conductive hearing loss in the presence of an intact tympanic membrane and an aerated middle ear and seems to be of similar sensitivity and specificity to measurements of VU plus audiometry. Additional research is needed to expand upon these promising preliminary results.

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COMPARISON OF EAR-CANAL REFLECTANCE AND UMBO VELOCITY IN PATIENTS WITH CONDUCTIVE HEARING LOSS: A PRELIMINARY STUDY

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ABSTRACT

Objective: The goal of the present study was to investigate the clinical utility of measurements of ear-canal reflectance (ECR) in a population of patients with conductive hearing loss in the presence of an intact, healthy tympanic membrane (TM) and an aerated middle ear. We also sought to compare the diagnostic accuracy of umbo velocity (V_U) measurements and measurements of ECR in the same group of patients.

Design: This prospective study comprised 31 adult patients with conductive hearing loss, of which 14 had surgically-confirmed stapes fixation due to otosclerosis, 6 had surgically-confirmed ossicular discontinuity, and 11 had CT- and VEMP-confirmed superior semicircular canal dehiscence (SCD). Measurements on all 31 ears included pure-tone audiometry for 0.25 – 8 kHz, ECR for 0.2 – 6 kHz using the Mimosa Acoustics HearID system, and V_U for 0.3 – 6 kHz using the HLV-1000 laser Doppler vibrometer (Polytec Inc). We analyzed power reflectance $|ECR|^2$ as well as the transmittance $= 10 \times \log_{10}(1 - |ECR|^2)$. All measurements were made prior to any surgical intervention. The V_U and ECR data were plotted against normative data obtained in a companion study of 58 strictly defined normal ears (Rosowski et al. 2011).

Results: Small increases in $|ECR|^2$ at low-to-mid frequencies were observed in cases with stapes fixation, while narrow-band decreases were seen for both SCD and ossicular discontinuity. The SCD and ossicular discontinuity differed in that the SCD had smaller decreases at mid-frequency, while ossicular discontinuity had larger decreases at lower

frequencies. SCD tended to have less air-bone gap at high frequencies compared to stapes fixation and ossicular discontinuity. The $|ECR|^2$ measurements, in conjunction with audiometry, could successfully separate 28 of the 31 cases into the three pathologies. By comparison, V_U measurements, in conjunction with audiometry, could successfully separate various pathologies in 29 of 31 cases.

Conclusions: The combination of $|ECR|^2$ with audiometry showed clinical utility in the differential diagnosis of conductive hearing loss in the presence of an intact TM and an aerated middle ear, and appears to be of similar sensitivity and specificity to measurements of V_U plus audiometry. Additional research is needed to expand upon these promising preliminary results.

INTRODUCTION

It is common to see patients in an otologic practice who have conductive hearing loss (defined as an air-bone gap on audiometry) in the presence of an intact, healthy tympanic membrane (TM) and an aerated middle ear. The vast majority of such cases result from one of three pathologic conditions: ossicular fixation, ossicular discontinuity, or a third window lesion of the inner ear (Merchant and Rosowski 2010). In the general clinic most cases of ossicular fixation result from a fixed stapes due to otosclerosis, while the majority of third window lesions are patients with superior semicircular canal dehiscence (SCD). The most common site of ossicular discontinuity is between the incus and stapes; the discontinuity may be complete, with no contact between the disconnected ends, or partial, wherein normal bony continuity is replaced by a band of fibrous tissue.

In contemporary clinical practice, there are no diagnostic tests that can reliably differentiate between the pathologic conditions described above. The size and frequency-dependence of the air-bone gap on standard audiometry shows large variations within and among these disorders, so that the audiogram alone cannot provide a differential diagnosis (Rappaport and Provencal 2002). Stapes fixation, partial discontinuity and SCD cannot be reliably distinguished by tympanometry (Harford 1980, Fowler and Shanks 2002). A computed tomographic (CT) scan is of diagnostic value for third window lesions such as SCD, but its resolution at present is not sufficient to permit reliable diagnosis of ossicular pathology (Chakers and Augustyn 2003). CT is also relatively expensive and involves exposure of patients to radiation; hence it is not practical to subject every patient with conductive hearing loss to a CT scan. Presence or absence of acoustic reflex is useful to distinguish ossicular disorders from third-window lesions (Minor 2005), but it does not help differentiate between ossicular fixation and discontinuity. Vestibular evoked myogenic potential (VEMP) testing is helpful in diagnosing SCD (Minor 2005), but cannot differentiate or diagnose ossicular pathologies; moreover, VEMP testing is not widely available.

A diagnostic test that differentiates among these disorders and that can be used in an office setting would be of clinical value. Patients with a third window lesion would be spared unnecessary surgical exploration of the middle ear. Furthermore, pre-surgical knowledge of the type of ossicular pathology likely to be encountered at surgery (e.g., stapes fixation versus ossicular discontinuity) would help an otologist in preoperative counseling of patients regarding surgical risks and in preoperative planning.

In 1999, Polytec Inc. (Waldbronn, Germany) introduced its HLV-1000 laser Doppler vibrometer (LDV) as a new diagnostic tool for measurement of sound-induced umbo velocity (V_U). The umbo is the most inferior part of the manubrium of the malleus that is attached near the center of the pars tensa of the tympanic membrane in humans. Our group and others have demonstrated that V_U measurement, coupled with audiometry, enables reliable pre-surgical differentiation among ossicular fixations, ossicular discontinuity and third window disorders

(Goode et al. 1996; Jorge-Rodriguez et al. 1997; Huber et al. 2001; Rosowski et al. 2003, 2008). Otologists from our institution and others in the Boston area often refer patients with conductive hearing loss to our laboratory for diagnostic testing using V_U measurements and pre-surgical assessment. However, there are practical limitations with V_U measurements. The LDV systems that are commercially available are not FDA approved for clinical application and are therefore restricted to research laboratories, such as ours. Measuring V_U requires a clinician with comfort and experience in oto-microscopy, i.e. skill is required to successfully and consistently aim the laser on the umbo. Furthermore, a second professional is typically needed to make V_U measurements: a trained computer operator to gather and evaluate the data. The relatively high cost (~ \$100,000) of the Polytec device is an additional limiting factor.

Ear-canal reflectance (ECR) is a variation of clinical acoustic immittance testing that has been described by many investigators (Keefe et al. 1993; Voss and Allen 1994; Hunter and Margolis 1997; Puria and Allen, 1998; Feeney and Keefe, 1999, 2001; Feeney et al. 2003; Feeney and Sanford, 2004; Allen et al. 2005). Power reflectance, the square of the magnitude of ECR ($|ECR|^2$) is the fraction of the incident acoustic power that is reflected by the tympanic membrane back into the ear canal (see the companion paper for a detailed description, Rosowski et al. 2011). ECR measurements can be performed with a commercially-available, relatively inexpensive device (~ \$10,000 for the Mimosa device) that received FDA approval in 2006 for clinical use; the device has been used by several groups (Allen et al. 2005; Shahnaz and Bork, 2006; Van der Werff et al. 2007; Withnel et al. 2009; Hunter et al. 2010; Voss et al. 2008). The Mimosa device requires minimal training and ECR measurements can be performed by a single individual. We have used this device to make ECR measurements in normal and pathological ears over the course of the past 18 months. As described in a companion paper (Rosowski et al. 2011), a practical difficulty we faced with the Mimosa device was calibrating the foam inserts. However, once calibration was successful, the measurements were straightforward and simple to perform.

Power reflectance has shown promise in the differential diagnosis of some middle ear disorders. For example, Feeney et al. (2003) presented $|ECR|^2$ data from two patients with stapes fixation due to otosclerosis and one patient with ossicular discontinuity showing distinct diagnostic patterns of $|ECR|^2$ in the two conditions. Allen et al. (2005) presented data from a patient with bilateral stapes fixation due to otosclerosis. Shahnaz et al. (2009) presented data from 28 patients with stapes fixation due to otosclerosis, and described how $|ECR|^2$ was of diagnostic value in differentiating otosclerotic ears from normal ears. However, it has not been determined whether $|ECR|^2$ can perform well in differentiating among various pathologies, as would be desired in a clinical setting.

The goal of the present study was to investigate the clinical utility of $|ECR|^2$ measurements in a population of patients with conductive hearing loss (due to different etiologies) in the presence of an intact, healthy TM and an aerated middle ear. We also sought to compare the diagnostic accuracy of V_U measurements (which we have been using for many years) and measurements of $|ECR|^2$ in the same patients.

MATERIAL AND METHODS

This prospective study was approved by the institutional review board of the Massachusetts Eye and Ear Infirmary (MEEI). The material consisted of 104 patients referred to our laboratory for V_U and ECR measurements from the Adult Otology Clinic at MEEI between November 2009 and February 2011. To be included in the present analysis, patients had to meet the following criteria: (1) an air bone gap on pure-tone audiometry; (2) an intact and healthy tympanic membrane consistent with an aerated middle ear on otoscopic examination;

(3) a diagnosis of stapes fixation, ossicular discontinuity or SCD made subsequent to our measurements, as described below.

Ears with stapes fixation were included if the diagnosis was confirmed at subsequent surgery, and the post-stapedectomy air-bone gap was less than 10 dB averaged over the frequencies 500, 1000, and 2000 Hz (thus ensuring that other potentially confounding pathologies such as malleus fixation or a third window lesion were not responsible for some of the hearing loss). Ears with ossicular discontinuity were included if the diagnosis was confirmed at subsequent surgery. Ears with SCD were included if a high-resolution CT scan confirmed a dehiscence and if VEMP thresholds were abnormally sensitive (Minor 2005). Fourteen ears with stapes fixation due to otosclerosis, 6 ears with ossicular discontinuity (4 with complete, and 2 with partial discontinuity), and 11 ears with SCD met the criteria for inclusion and were analyzed in detail in the present study (a total of 31 ears). Among the 31 ears, the age range was 22 to 72 years; 15 were males and 16 were females. There were 11 right and 20 left ears.

Measurements on all 31 ears included pure-tone audiometry for 0.25 – 8 kHz, ECR for 0.2 – 6 kHz at 60 dB SPL using the Mimosa Acoustics HearID system, and V_U for 0.3 – 6 kHz at 70 – 90 dB SPL using the HLV-1000 laser Doppler vibrometer (Polytec Inc). In addition, 28/31 patients also had standard 220 Hz tympanometry, the exception being 3 ears with stapes fixation. The details of our measurement techniques for V_U and ECR are described in the companion paper (Rosowski et al. 2011). We analyzed $|ECR|^2$ as well as the transmittance = $10 \times \log_{10}(1 - |ECR|^2)$. $|ECR|^2$ describes the fraction of the incident power that is reflected at the TM. Transmittance is the dB descriptor of the fraction of incident power that is absorbed. The V_U and $|ECR|^2$ data were plotted against normative data obtained in the companion study of 58 strictly defined normal ears (Rosowski et al. 2011).

RESULTS

INSERT FIGURES 1-5 ABOUT HERE

Stapes fixation

Figures 1a and b show V_U measurements from 5 representative ears that include the largest [P049L] and smallest [P056L] V_U magnitudes (gray lines) among all 14 ears found to have stapes fixation. The gray shaded regions in Fig. 1 show normative data of \pm one standard deviation (SD) around the mean. Most V_U magnitudes in ears with fixed stapes were lower than the normal-hearing average at low frequencies, and the V_U phase tended to stay closer to 90 degrees at frequencies below 3 kHz as compared to normal. These results, indicative of a stiffer system, are similar to those previously published by us (Rosowski et al. 2008), and are also similar to V_U data after experimental stapes fixation in cadaveric temporal bones (Nakajima et al. 2004, 2005).

$|ECR|^2$ data for the same 5 representative patients are plotted in Fig. 1c. Generally, the $|ECR|^2$ was higher than normal at low frequencies (400-1000 Hz), indicative of a stiffer system. We also observed an inverse relationship between V_U and power reflectance. The ear with largest V_U at frequencies less than 3 kHz (P049L) had the lowest $|ECR|^2$ between 0.4 and 1.5 kHz. The ear with the lowest V_U magnitude (P056L) had the highest $|ECR|^2$ over the same frequency range. Transmittance is plotted in Fig. 1d for the same 5 ears, and had a tendency to be lower than the normal-hearing mean at low frequencies. Generally, the V_U , $|ECR|^2$ and transmittance showed results that were consistent with a stiffer system, except for ear P049L which had a more compliant system than the normal mean. The two ears, [P049 L, the most compliant] and [P056L, the most stiff] were consistently the two extreme outliers for all three measurements, V_U , $|ECR|^2$ and transmittance. The most compliant ear [P049 L] had a tympanogram that was normal, and the stiffest ear [P056 L] had a round-shaped tympanogram, consistent with a stiffer-than-normal system.

The mean \pm one SD of the V_U measurements for all 14 patients with stapes fixation are plotted in Fig. 4a & b with red lines, revealing an average reduction in V_U magnitude of approximately 2 standard deviations from normal mean for frequencies below 1 kHz. The average phase was near 90 degrees at higher frequencies compared to normal. Both magnitude and phase data are consistent with a stiffer system. Mean $|ECR|^2$ showed a small increase and mean transmittance showed a small decrease for frequencies below 1 kHz compared to the normal-hearing mean, as shown in Figs. 4 c & d (red lines). The $|ECR|^2$ results are similar to Shahnaz et al. (2009). There are large regions of overlap between the mean \pm 1 SD ranges of the normal and fixed-stapes measurements in all four panels of Figure 4..

The mean of the air-bone gaps are plotted in Fig. 5. Stapes fixation (red line) showed large conductive losses (40 – 60 dB) at low frequencies, with smaller air-bone gaps at high frequencies (~20 dB). Of the 11 patients who underwent tympanometry, 10 had a normal tympanogram; one ear [P056L] had a round-shaped tympanogram, consistent with a tympanic membrane and/or ossicular chain that was stiffer than normal.

Ossicular Discontinuity

There were 6 ears with discontinuity of the ossicular chain. Five of the 6 had normal tympanograms; one ear [P054R] had an abnormally round-shaped tympanogram, consistent with a middle-ear system stiffer than normal. Figures 2a and b show plots of the V_U magnitudes for all 6 ears with ossicular discontinuity, with gray lines to indicate the most extreme outliers. Five out of the 6 individuals showed an increase of V_U magnitude of more than two standard deviations from normal mean at frequencies below 1 kHz, and V_U phase that decreased abruptly around 400-800 Hz, similar to previous results (Rosowski et al. 2008). One ear, (P054R, with a round-shaped tympanogram) had a low V_U magnitude without an abrupt decrease in phase, consistent with a stiffened system. Four ears had complete (solid lines) and two had partial (dashed lines) ossicular discontinuity. There was a tendency for V_U magnitude to be higher and phase to change abruptly at lower frequencies for complete discontinuity as compared to partial discontinuity.

ECR measurements showed a notch in $|ECR|^2$ and a peak in transmittance between 500 Hz and 800 Hz in 5 of the 6 ears with discontinuity (Figs. 2c and d). These results are similar to that published for one case by Feeney et al. (2003). The large notch in $|ECR|^2$ and peak in transmittance are consistent with a compliant system. The one ear with the round-shaped (stiffer) tympanogram (P054R, gray dotted line) did not have this notch or peak in the $|ECR|^2$ or transmittance, respectively, and was the same ear in which the V_U was of low magnitude and phase that stayed near 90 degrees for higher frequencies, consistent with a stiffer system. $|ECR|^2$ for complete discontinuity (solid lines) was lower than for partial discontinuity (dashed lines) around 500-600 Hz. Measurements of V_U , $|ECR|^2$ and transmittance were consistent in that ear P054R (with the rounded tympanogram peak), in that all three measurements showed a stiffer than normal characteristic.

Figures 4a and b show the mean V_U for the 6 ears with ossicular discontinuity (blue lines); the mean magnitude was more than 2 standard deviations above the normal mean below 1 kHz, while phase decreased abruptly at low frequencies. The mean $|ECR|^2$ (Figs. 4c and d) of these 6 ears in the area of the notch (600-800 Hz) was more than two SD below that of normal subjects. Thus, both V_U and $|ECR|^2$ measurements by themselves can generally separate the ears with discontinuity of the ossicular chain from normal ears.

The mean air-bone gap for ossicular discontinuity is plotted in Fig. 5 with a blue line. Similar to stapes fixation, ossicular discontinuity resulted in large air-bone gaps (40-60 dB) at low frequencies. However, at higher frequencies the air-bone gap for ossicular discontinuity was larger than for stapes fixation.

Superior Semicircular Canal Dehiscence (SCD)

All 11 ears with SCD had normal tympanograms. Figure 3 shows 6 representative ears with SCD, including the most extreme magnitudes of V_U [P103R, P080R plotted with gray lines] and $|ECR|^2$ [P074L, P082L]. Note that unlike stapes-fixation or ossicular interruption, the ears with extreme measurement values in V_U were not extreme in power reflectance or transmittance. Most measurements of V_U had a magnitude larger than the mean and a phase somewhat smaller than the mean at frequencies near and below 1 kHz, similar to previous data (Rosowski et al. 2008). The $|ECR|^2$ measurements showed a notch with a value about two standard deviations below the normal mean at frequencies between 750 Hz and 1000 Hz.

The mean SCD data for all 11 ears are plotted in Fig. 4, showing that SCD generally caused an increase in V_U magnitude and a more abrupt decrease in V_U phase around 1 kHz compared to the normal mean. SCD also caused a notch/decrease in $|ECR|^2$ or peak/increase in transmittance at around 1 kHz. Because of the overlap between normal and pathologic results, V_U measurements in ears with SCD were only slightly different from those in normal ears. $|ECR|^2$ measurements near 750-1000 Hz in SCD were more distinguishable from normal on average, but there was also significant overlap between normal and SCD ears. In general, the differences in V_U , power reflectance and transmittance that we observe between normal and SCD ears are reduced versions of the differences observed between normals and ears with ossicular interruption, with changes occurring at higher frequencies for SCD compared to ossicular discontinuity.

The air-bone gaps experienced by SCD patients were more pronounced at low frequencies than at high frequencies (Fig. 5), and were smaller (by about 20 dB) when compared to the gaps produced by fixation or interruption at the same frequency.

DISCUSSION

We made pre-diagnostic measurements comprising audiometry, tympanometry, V_U and $|ECR|^2$ in 31 patients with conductive hearing loss. These 31 patients were ultimately diagnosed as having stapes fixation, ossicular discontinuity or superior canal dehiscence as the cause of their air-bone gap. The three pathologies investigated in the study are representative of the majority of cases of conductive hearing losses seen in patients who have a healthy tympanic membrane and an aerated middle ear on otoscopic exam.

The data showed large overlaps in the size and frequency dependence of air-bone gaps within and between the three pathologies, so that audiometry by itself did not permit accurate preoperative diagnosis of the etiology for the conductive loss. Similarly, tympanometry was not sensitive in diagnosing the ears studied: 10 of 11 ears with fixed stapes, 5 of 6 with ossicular discontinuity and all 11 ears with SCD had normal tympanograms. Furthermore, the one ear with an abnormal tympanogram and interrupted ossicular chain actually had a round-shaped tympanogram, consistent with a stiffer middle ear, which would suggest fixation rather than the true diagnosis. As can be seen in Fig. 4, although V_U and $|ECR|^2$ showed a clearly distinctive pattern for ossicular discontinuity, there was sufficient overlap between the fixed stapes and SCD cases such that neither V_U nor $|ECR|^2$ could serve as a stand-alone diagnostic tool to separate out the three pathologic conditions.

INSERT FIGURE 6 ABOUT HERE

We have shown in the past that V_U measurements in conjunction with audiometric data can differentiate various pathologies that cause conductive hearing loss (Rosowski et al. 2008). We performed a similar analysis for the dataset in the present study. In Figure 6, we show plots of umbo velocity (in 6a) or transmittance (in 6b) versus the air-bone gap in all 31 ears. In Fig.

6a, for each ear, V_U magnitudes measured for the ears with conductive hearing loss normalized to the V_U magnitudes of normal-hearing mean (averaged over 300 – 700 Hz) were plotted against the air-bone gap (averaged over 1 – 4 kHz). The different symbols represent each of the three pathologies. It can be appreciated from the boundaries drawn that 29 of the 31 ears were easily separated into the three pathological groups. Exceptions included one ear with a fixed stapes that fell into the ossicular discontinuity area, and one ossicular discontinuity in the stapes fixation area. The choice of the 1 – 4 kHz range for the average air-bone gap was dictated by the range where we saw large differences between the three pathologies. Similarly, the V_U magnitudes had the most separation between the three pathologies between 300 – 700 Hz.

A similar scatter plot (Fig. 6b) was made for transmittance measurements where each ear was referenced to the normal-hearing mean (averaged over 0.6 – 1 kHz), and plotted against the air-bone gap (averaged over 1 – 4 kHz). Figure 4d demonstrates that transmittance data for the three pathologies were most different from each other in the 0.6 – 1 kHz range. Using transmittance in combination with the air-bone gap also separated 28 of the 31 ears into the three pathological groups. There were 3 exceptions: 1 stapes fixation fell into the area bounded by ossicular discontinuity, 1 ossicular discontinuity fell between the SCD and stapes fixation area, and 1 stapes fixation fell on the border of the SCD area. The fixed stapes ear that was in the ossicular discontinuity area for both the V_U and transmittance scatter plots was ear [P049L], which had both V_U and transmittance measurements that were consistent with a compliant system (Fig. 1, discussed in the results section). The ossicular discontinuity that was at the border of the stapes fixation area in the V_U scatter plot (Fig. 6a) and between the SCD and stapes fixation area in the transmittance scatter plot (Fig. 6b), was ear [P054R], that had the tympanogram, V_U and transmittance measurements consistent with a stiffer system (Fig. 2, discussed in the results section).

The simple analysis shown in Fig. 6 illustrates that either V_U or transmittance, in conjunction with audiometric data, was able to correctly identify nearly all of the ears into the three different pathologies. If the detection of each pathology was determined by the boundaries drawn around the various areas in Fig. 6, then the computed sensitivity and specificity are shown in Table 1. In the definition of stapes fixation, umbo velocity had slightly higher sensitivity but lower specificity than transmittance. For ossicular discontinuity, umbo velocity and transmittance had the same sensitivity and specificity. For SCD, umbo velocity had the same sensitivity, but slightly higher specificity than transmittance. Overall, for both types of diagnostic measurements, the range of sensitivity was 83-100% and specificity 94-100%.

We point out that the diagnostic scheme shown in Figure 6 uses a two-dimensional approach where the separation of the 3 pathologies is based on the combination of air-bone gap and transmittance or umbo velocity. Use of the air bone gap in the diagnostic scheme appears to be more critical for transmittance than for umbo velocity. Thus, a hypothetical patient with early stapes fixation who has a small air-bone gap may show overlap with SCD with respect to transmittance. In such a case, differentiation between the two pathologies might be achieved by looking at the shape of the power reflectance data. For example, SCD shows a notch (narrow-band decrease) around 1000 Hz and ossicular discontinuity shows a larger notch at lower frequencies, while stapes fixation shows a slight increase at mid-to-low frequencies (see Figure 4b). Thus, in addition to the simple scheme shown in Figure 6, there may be more refined analytical methods that may yield more sensitive and specific separations.

This preliminary study demonstrates that *ECR* measurements have promise in differential diagnosis of pathologies causing conductive hearing loss in the setting of an intact and healthy TM, and an aerated middle ear by otoscopy. Additional measurements are needed using a greater number of patients, so as to further test these preliminary results. Future research is also needed to determine the diagnostic value of *ECR* measurements in other types

of middle ear disorders such as malleus fixation, perforations and other abnormalities of the tympanic membrane, and effusions of the middle ear.

CONCLUSIONS

There is clinical value in being able to pre-surgically diagnose the cause of a conductive hearing loss in the setting of an intact tympanic membrane and an aerated middle ear. The frequency dependence of the power reflectance measurements was different for the three pathologies: stapes fixation resulted in small increase from normal at low-to-mid frequencies, while large narrow-band decreases from normal were seen for ossicular discontinuity (between 500-800 Hz) and SCD (around 1 kHz). SCD tended to have less air-bone gap at high frequencies compared to stapes fixation and ossicular discontinuity. Power reflectance measurements with audiometry showed clinical utility in the differential diagnosis of these disorders, exhibiting high sensitivity and specificity, similar to measurements of umbo velocity plus audiometry. Additional research is needed to further investigate these promising preliminary results.

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Table 1 Sensitivity and Specificity of Umbo Velocity and Transmittance Measurements

Umbo Velocity with Air-Bone Gap Measurements

Pathology	Sensitivity	Specificity
Stapes Fixation	93%	94%
Ossicular Discontinuity	83%	96%
SCD	100%	100%

Transmittance with Air-Bone Gap Measurements

Pathology	Sensitivity	Specificity
Stapes Fixation	86%	100%
Ossicular Discontinuity	83%	96%
SCD	100%	95%

STAPES FIXATION

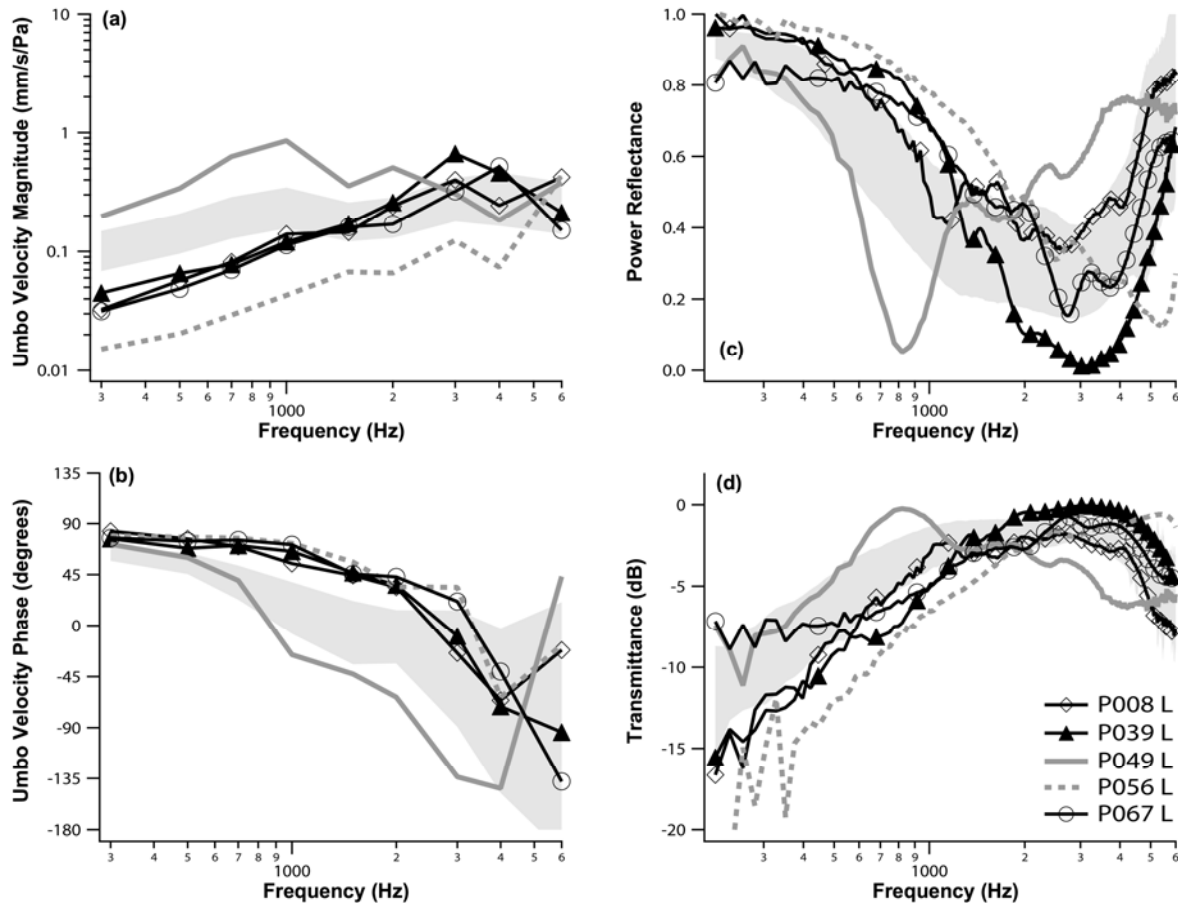


Figure 1.

Umbo velocity and ear-canal reflectance data for stapes fixation: Umbo velocity magnitude and phase referenced to ear-canal pressure are shown in panels (a) and (b), respectively. Power reflectance data are shown in panel (c), while transmittance is plotted in panel (d). All four panels display results from 5 representative ears, out of 14 measured. The 5 cases include the two ears (gray lines) that showed the most extreme measurements. The shaded region represents normative data of \pm one standard deviation around the normal mean.

OSSICULAR DISCONTINUITY

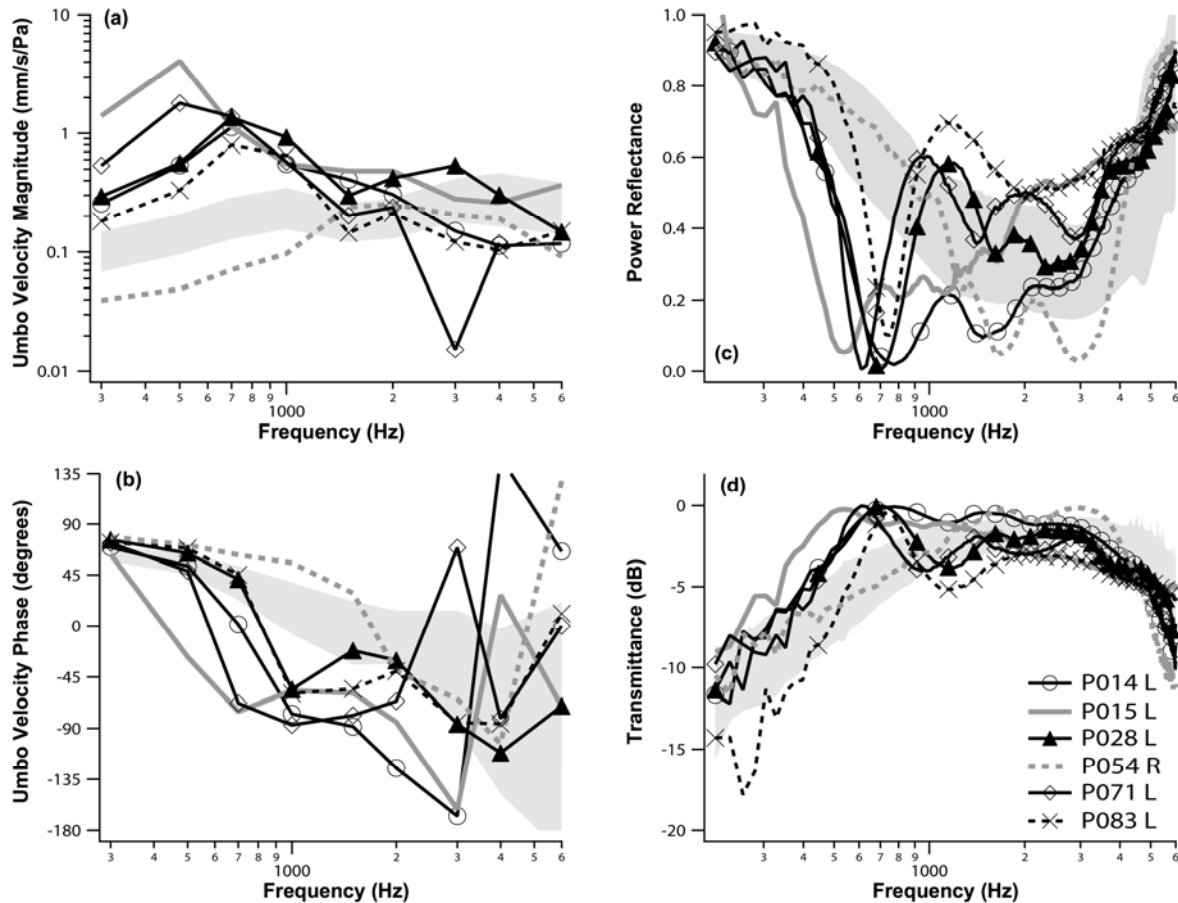


Figure 2

Umbo velocity and ear-canal reflectance data for ossicular discontinuity: Umbo velocity magnitude and phase referenced to ear-canal pressure are shown in panels (a) and (b), respectively. Power reflectance data are shown in panel (c), while transmittance is plotted in panel (d). All four panels display results from all 6 ears measured. The two ears that showed the most extreme measurements are plotted as gray lines. Solid lines signify complete discontinuity, while the dashed lines partial discontinuity. The shaded region represents normative data of \pm one standard deviation around the normal mean.

SUPERIOR SEMICIRCULAR CANAL DEHISCENCE

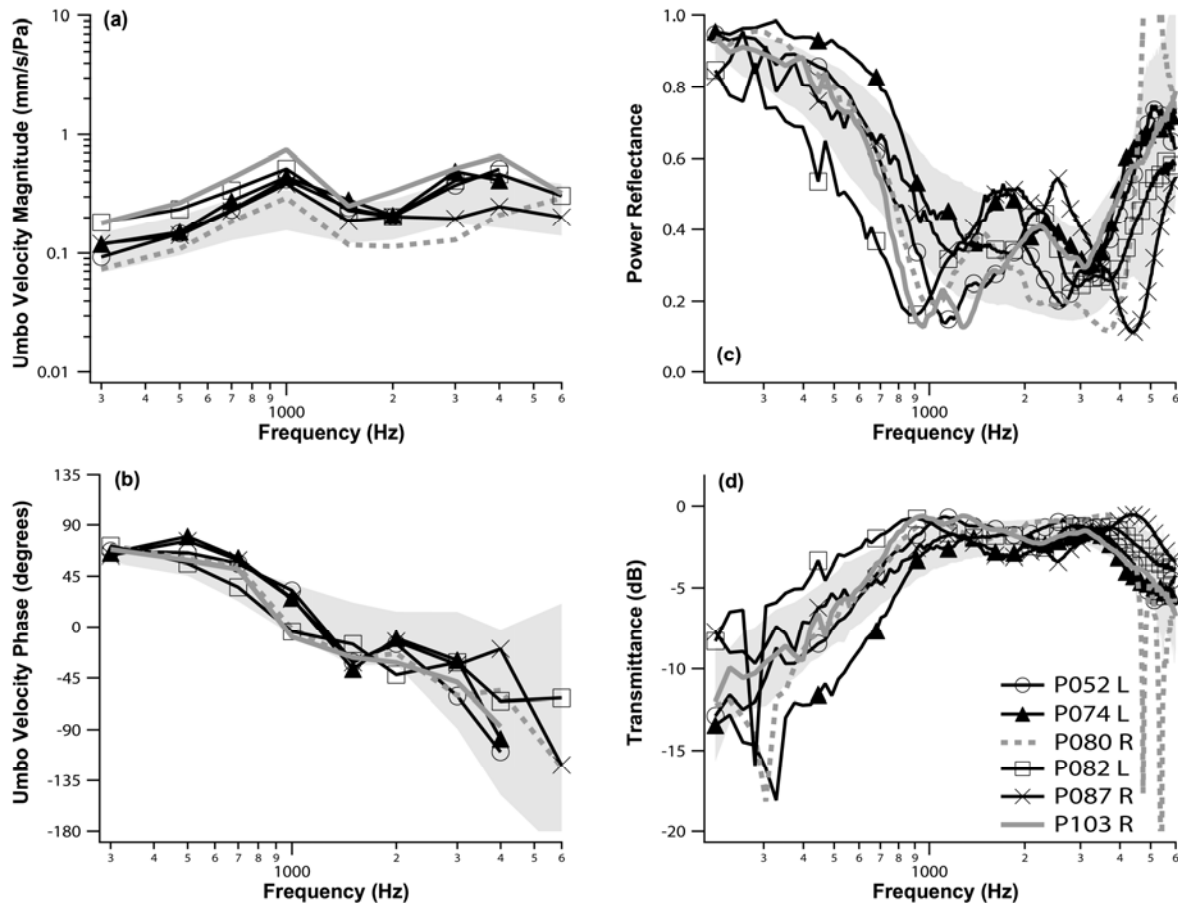


Figure 3

Umbo velocity and ear-canal reflectance data for superior semicircular canal dehiscence: Umbo velocity magnitude and phase referenced to ear-canal pressure are shown in panels (a) and (b), respectively. Power reflectance data are shown in panel (c), while transmittance is plotted in panel (d). All four panels display results from 6 representative ears, out of 11 measured. The gray lines depict the two ears that showed the most extreme umbo velocity magnitudes. The shaded region represents normative data of \pm one standard deviation around the normal mean.

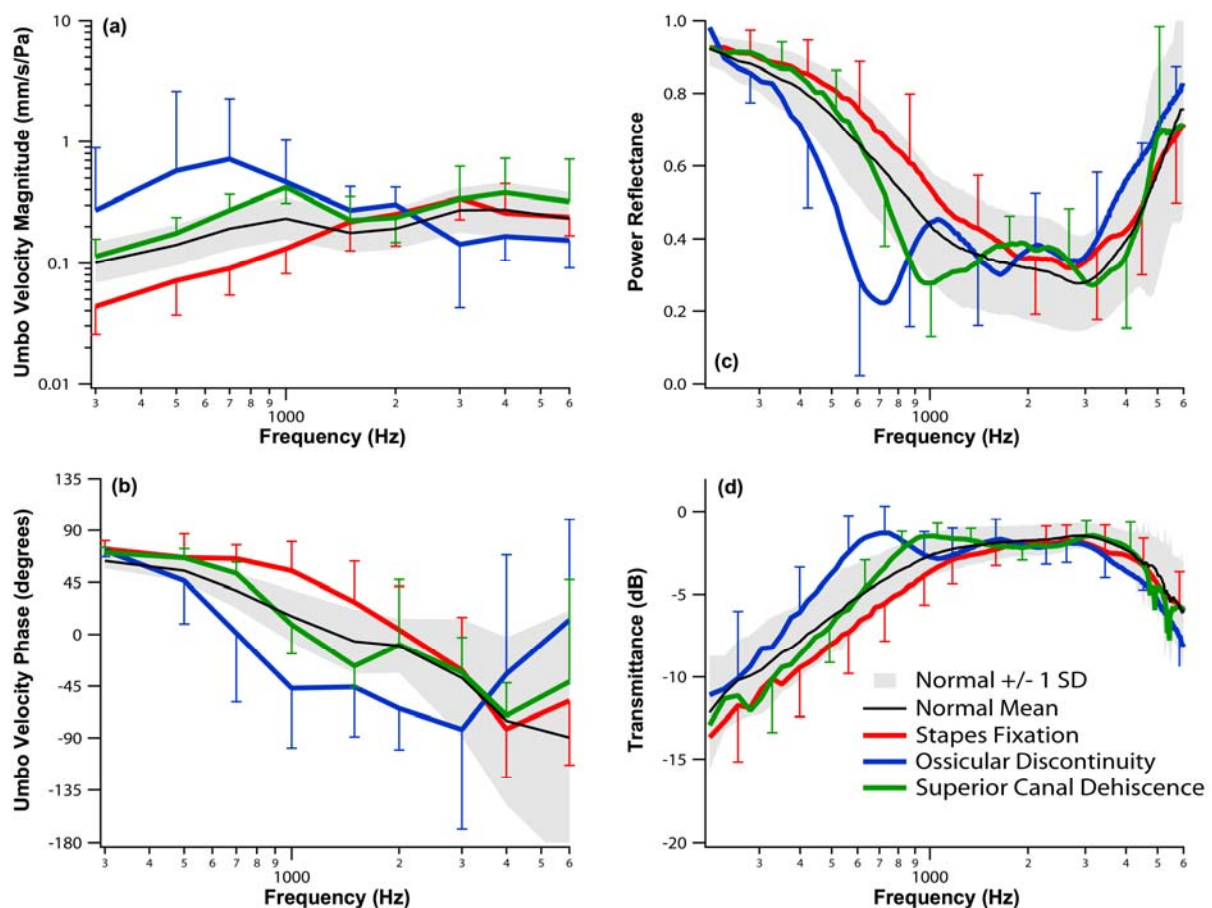


Figure 4

The mean ± 1 standard deviation (SD) of umbo velocity and power reflectance data for all 31 ears in the study are shown, displayed separately by diagnosis. There were 14 ears with stapes fixation (red), 6 ears with ossicular discontinuity (blue), and 11 ears with superior canal dehiscence (green). Umbo velocity magnitude and phase referenced to ear-canal pressure are shown in panels (a) and (b), respectively. Power reflectance data are shown in panel (c), while transmittance is plotted in panel (d). The shaded region represents normative data of ± 1 SD around the normal mean (black line).

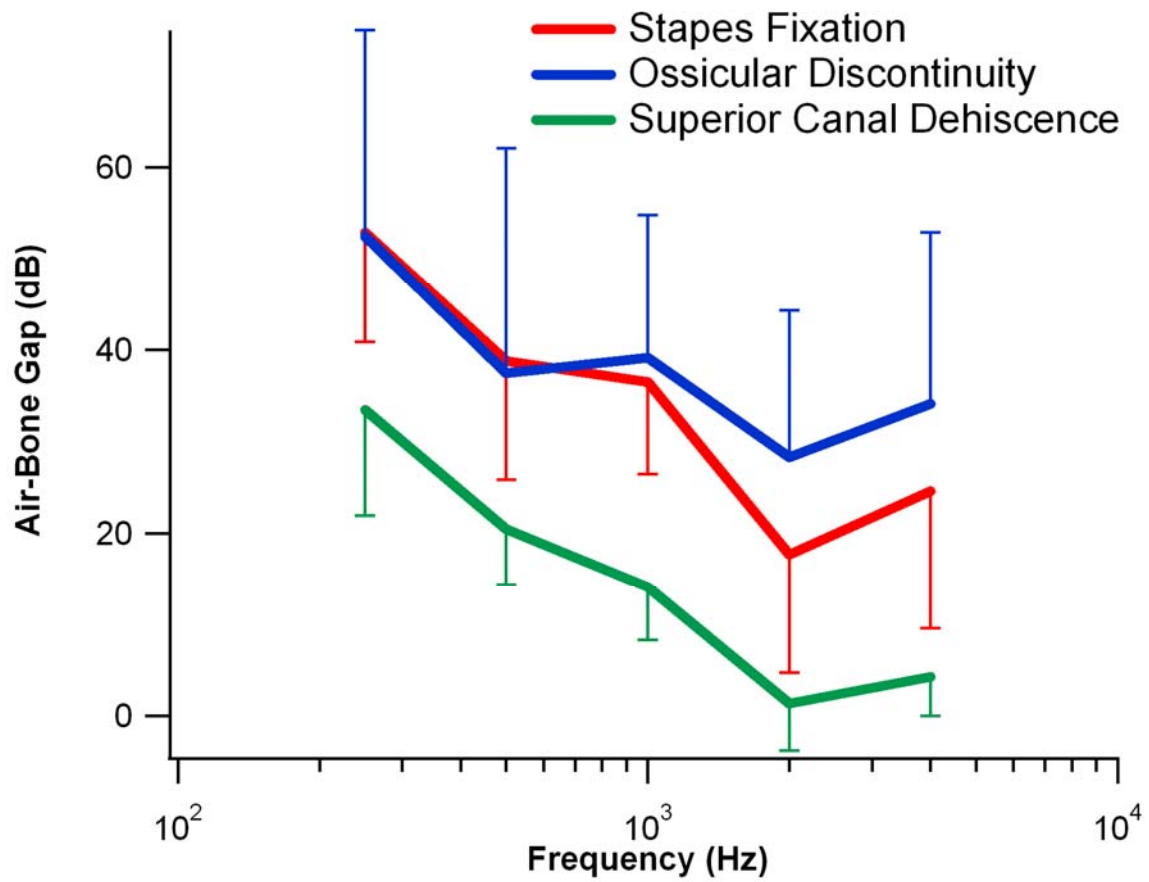


Figure 5

The mean ± 1 standard deviations of the air-bone gaps versus frequency for the 3 pathologic conditions are displayed. There were 14 ears with stapes fixation (red), 6 ears with ossicular discontinuity (blue), and 11 ears with superior canal dehiscence (green).

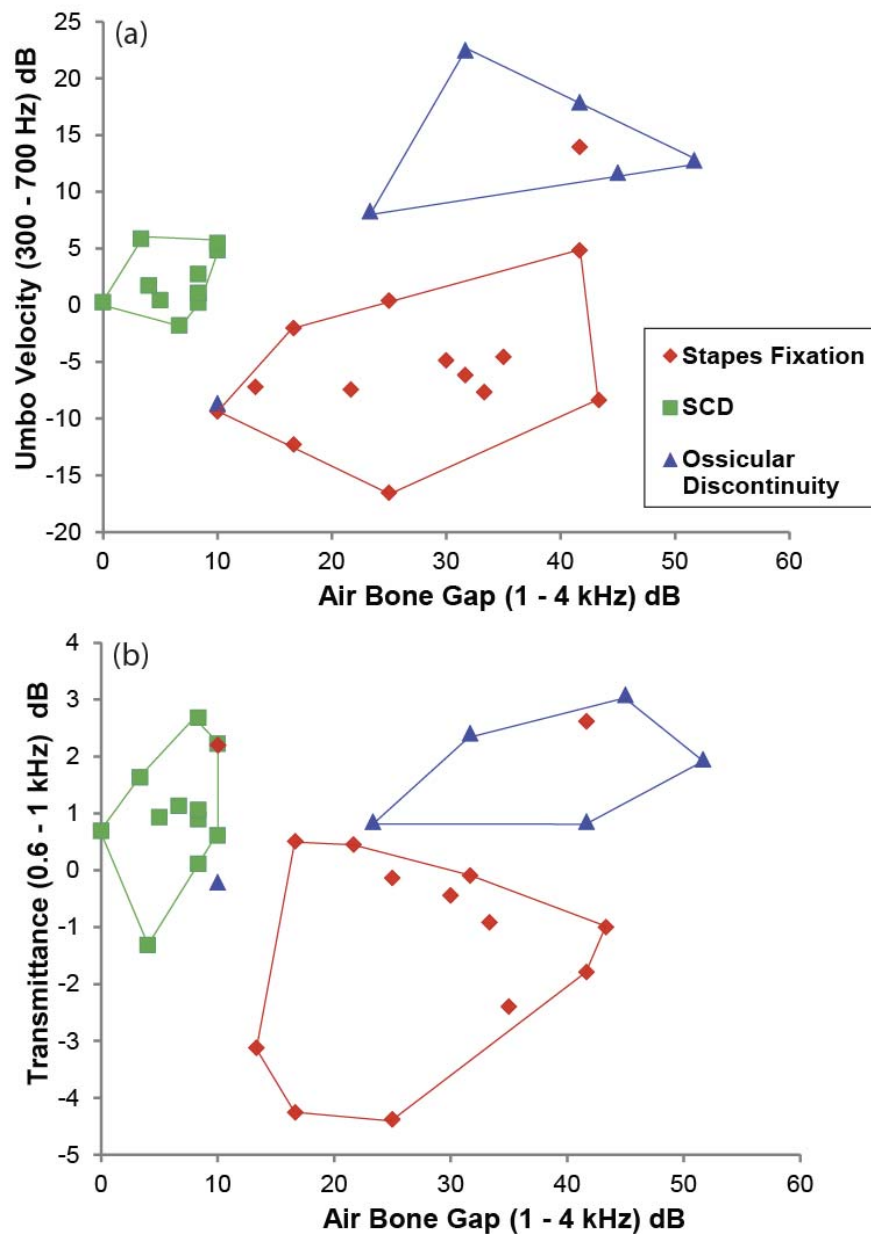


Figure 6

In top panel (a), Umbo velocity magnitudes referenced to the normal-hearing mean (averaged over 300-700 Hz) are plotted against the air bone gap (averaged over 1-4 kHz). The different symbols and colors represent each of the three pathologies. All three disorders were separable from each other for 29/31 ears. Exceptions included one ear with a fixed stapes in the ossicular discontinuity area, and one ossicular discontinuity in the stapes fixation area.

Bottom panel (b) shows transmittance measurements where each ear was referenced to the normal-hearing mean (averaged over 0.6-1 kHz), and plotted against the air-bone gap (averaged over 1-4 kHz). Using transmittance in combination with the air-bone gap also allowed separation of the 3 pathologies for 28/31 ears. There were 3 exceptions: 1 stapes fixation in the area bounded by ossicular discontinuity, 1 ossicular discontinuity not bounded by a particular pathology but in-between the SCD and stapes fixation area, and 1 stapes fixation that was at the border of the SCD area.